Material Selection Considerations in the Design of a Burst Reactor Core

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NCSP Technical Program Review

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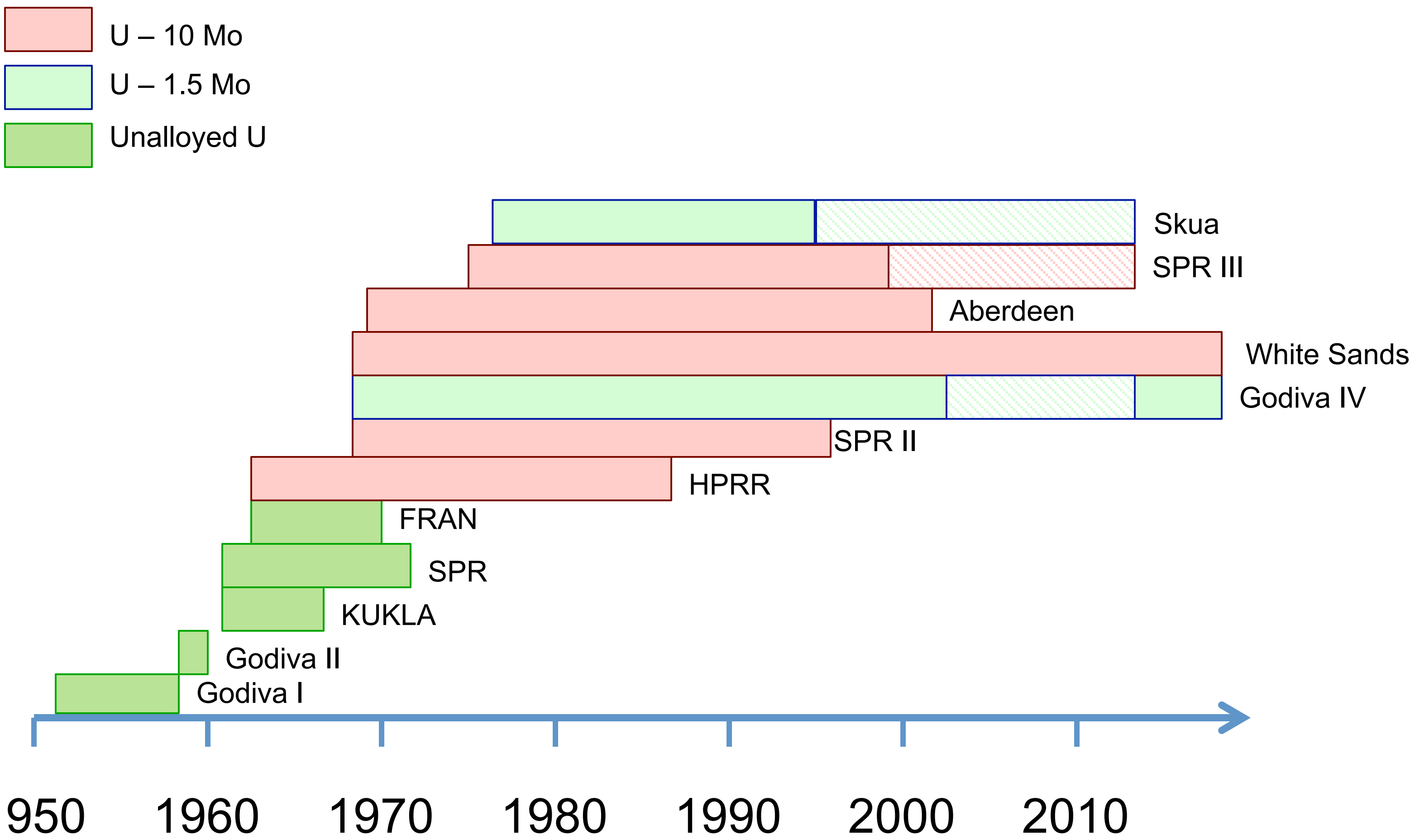
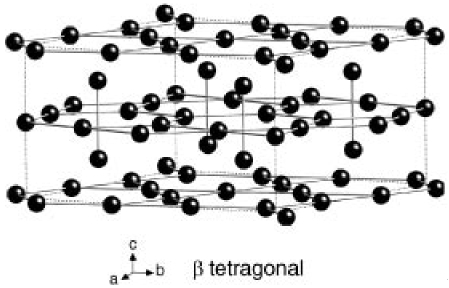
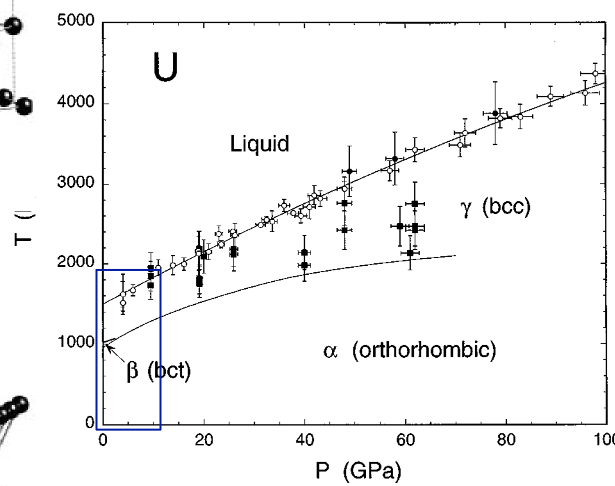
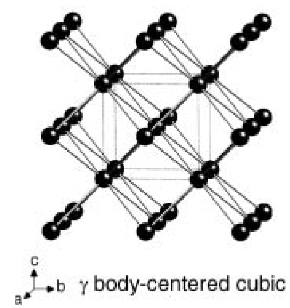
History of uranium alloy selection in Fast Burst Reactors

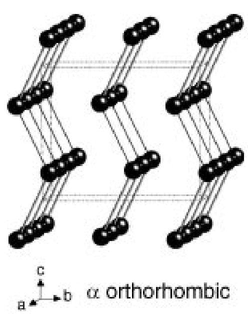


Unalloyed uranium has three allotropes









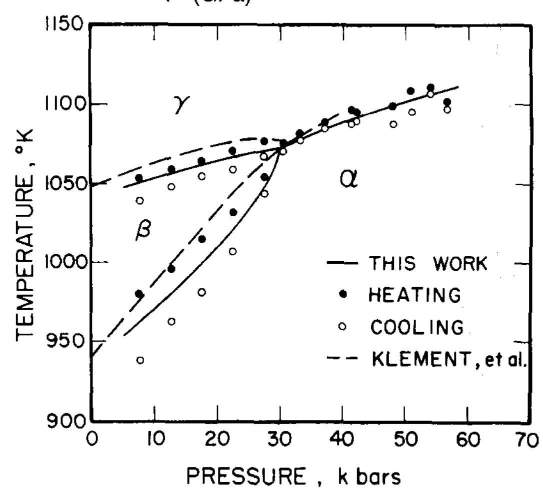


Fig. 1. The phase diagram of uranium.

One component (i.e., pure element, not alloy) phase transformations between allotropes takes place ~10^{-7} to 10^{-12} sec

Thermal cycling in unalloyed uranium results in permanent plastic deformation

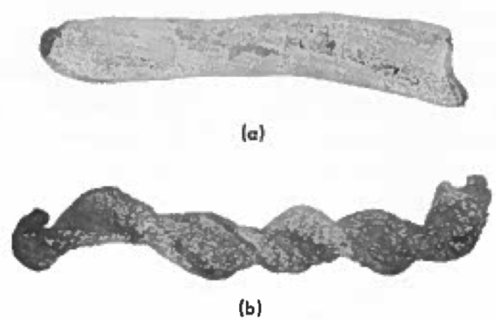


FIG. 12–1. Growth of uranium rod by thermal cycling from 100 to 500°C; original size $\frac{1}{2}$ inch long and $\frac{1}{4}$ inch in diameter. (a) 2132 cycles (2×); (b) 4882 cycles (2×).

FIG. 12–2. Thermal-cycling growth of highly oriented fine-grained uranium (300°C rolled rod). Growth from 2 to 11.5 inches by 300 cycles from 50 to 550°C.(16)

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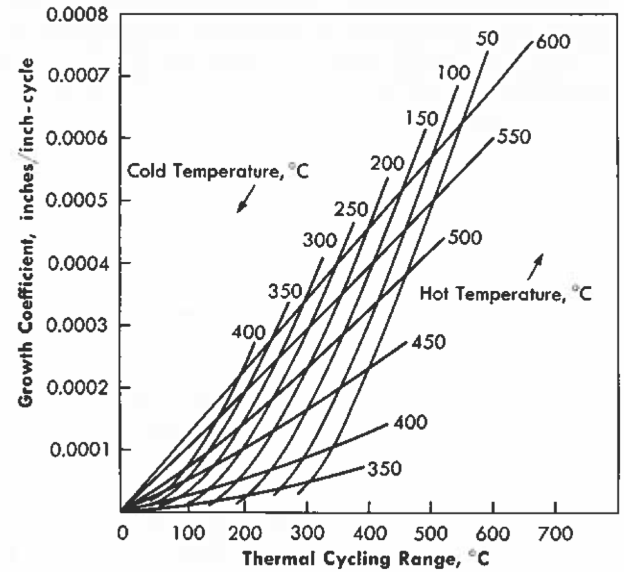


FIG. 12–6. Thermal-cycling range and temperatures effect on growth of uranium.(4)

Anisotropy of thermal expansion in alpha uranium

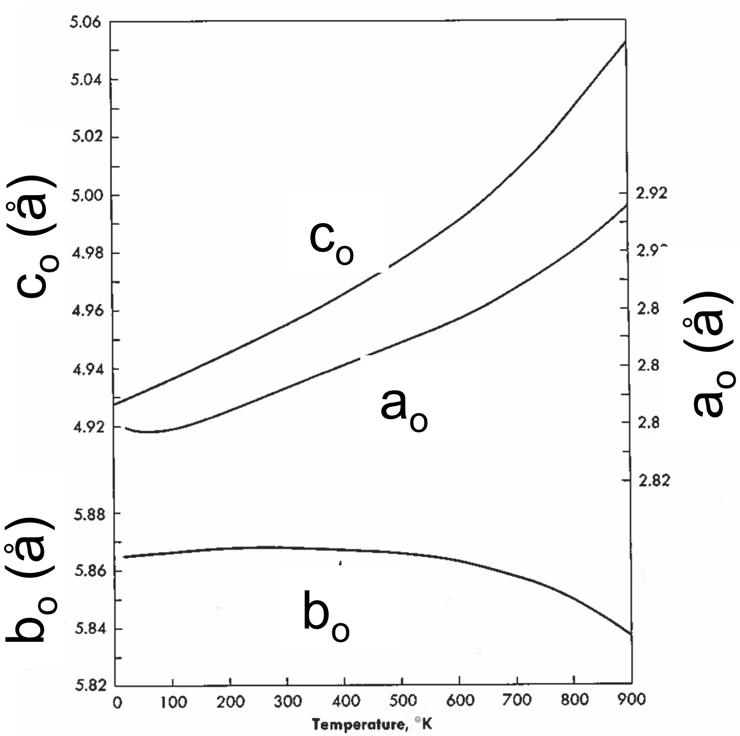


FIG. 4-1. Lattice parameters of uranium as a function of temperature (x-ray measurements).

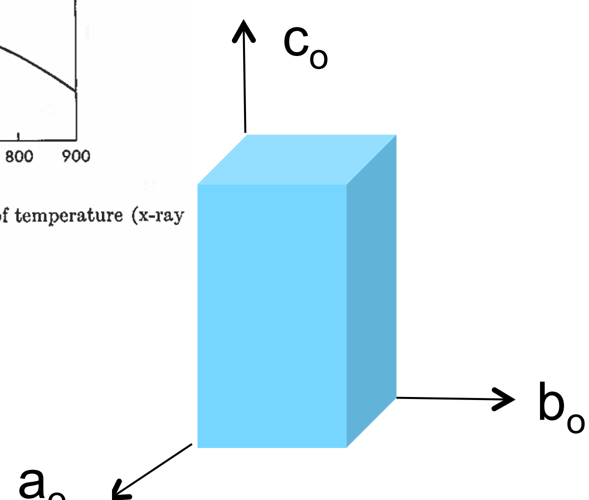
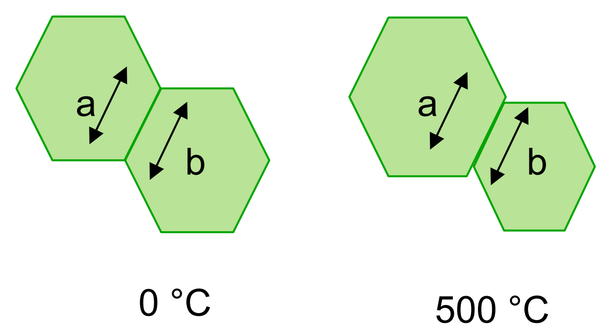


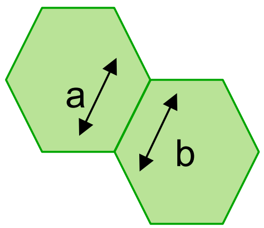
TABLE 4-3

CALCULATED THERMAL EXPANSION OF ALPHA URANIUM, 0–600°C

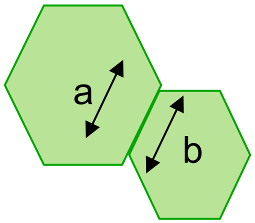
Temperature, °C	$\left(\frac{L_T - L_0}{L_0}\right) \times 100$, % Parallel to [100]	Parallel to [010]	Parallel to [001]	$\left(\frac{V_T - V_0}{V_0}\right) \times 100$, %
0	0	0	0	0
25	0.05	−0.002	0.05	0.09
50	0.10	−0.004	0.10	0.19
100	0.22	−0.007	0.21	0.39
200	0.48	−0.019	0.44	0.87
300	0.80	−0.052	0.70	1.42
400	1.17	−0.124	1.02	2.04
500	1.59	−0.250	1.40	2.73
600	2.07	−0.450	1.88	3.48



Thermal “ratcheting”



0 °C



500 °C

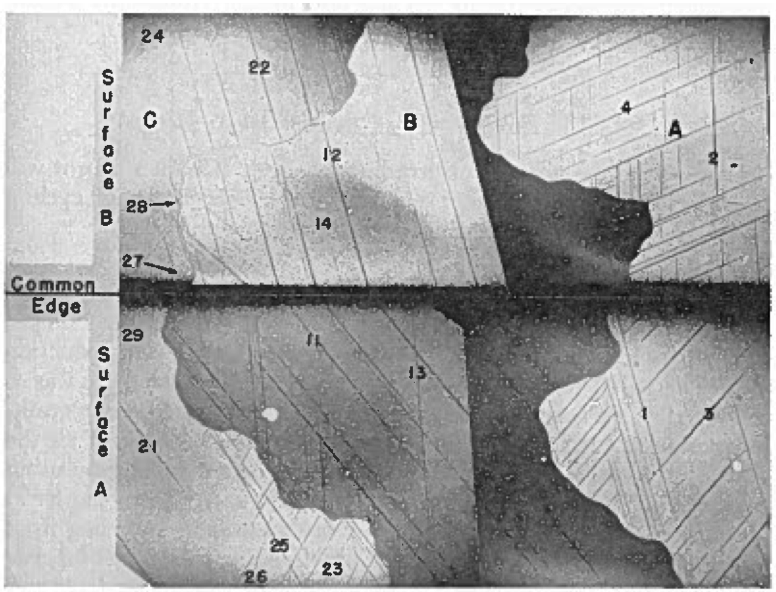


Figure 11.12. Polished section of high-purity coarse-grained uranium specimen before cycling (from L. T. Lloyd *et al.*[9], *by courtesy of American Society for Metals)*

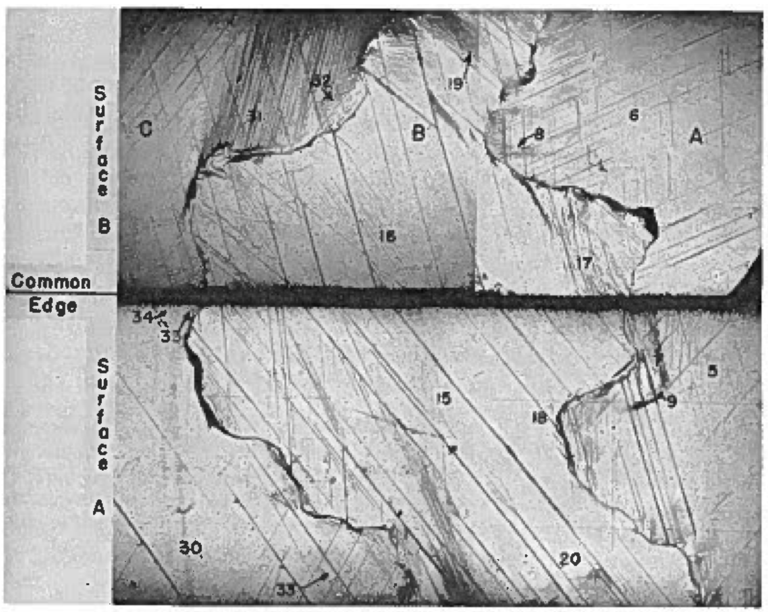


Figure 11.13. Specimen illustrated in Figure 11.12 after cycling from room temperature to 500°C *(from* L. T. Lloyd *et al.*[9], *by courtesy of American Society for Metals)*

Mo alloying additions can decrease effects of thermal cycling

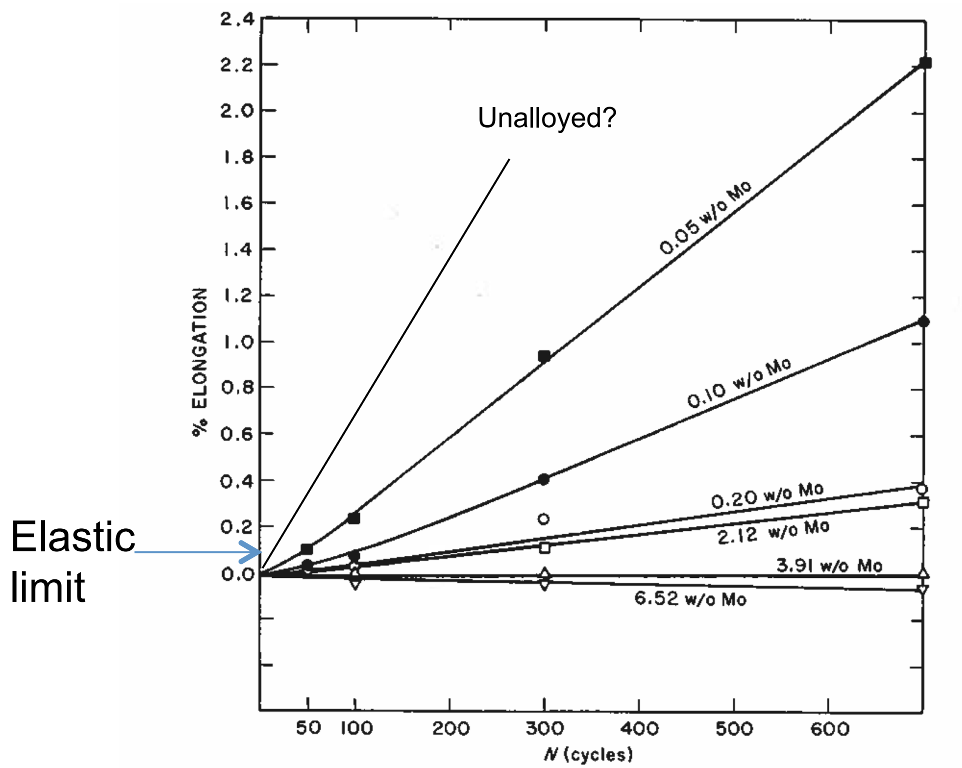


Fig. 21. Improvement of dimensional stability of uranium on standard thermal cycling by molybdenum additions of up to 2 w/o.[40]

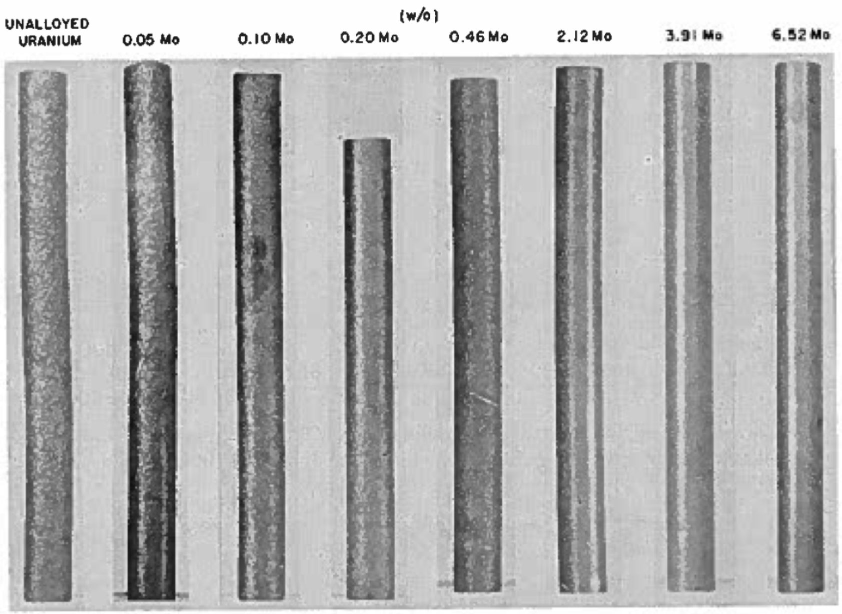
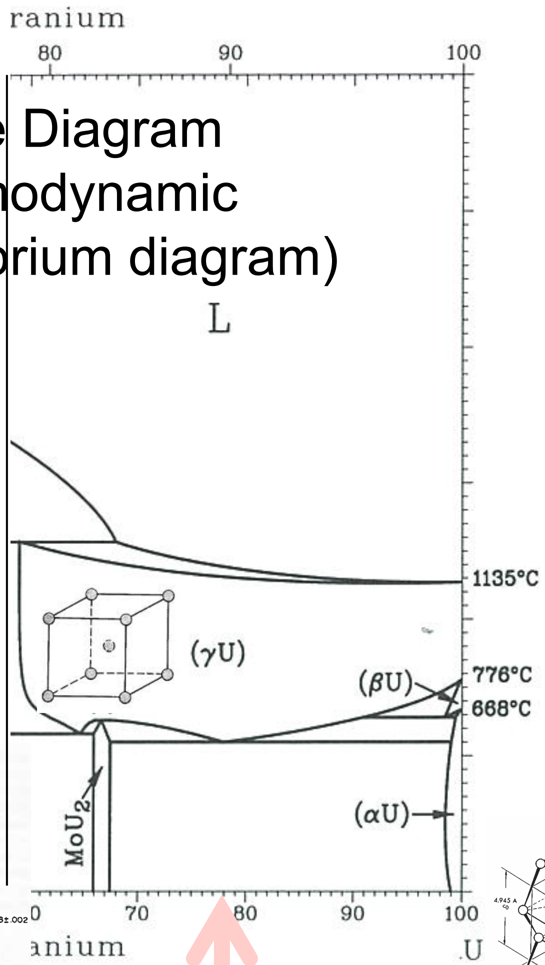


Fig. 22. Specimens of uranium-molybdenum alloys after 700 standard thermal cycles.[40] The surfaces of those containing a minimum of 2 w/o of molybdenum are unaffected.

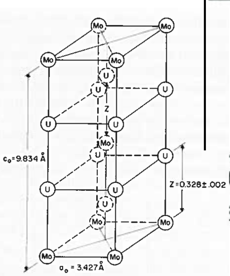
Thermal expansion for cubic phases are istotropic

U-10Mo provides for a very meta-stable phase

Phase Diagram
(thermodynamic
equilibrium diagram)



SPR-II



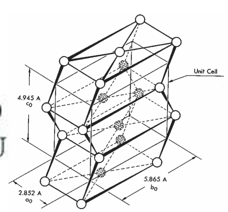
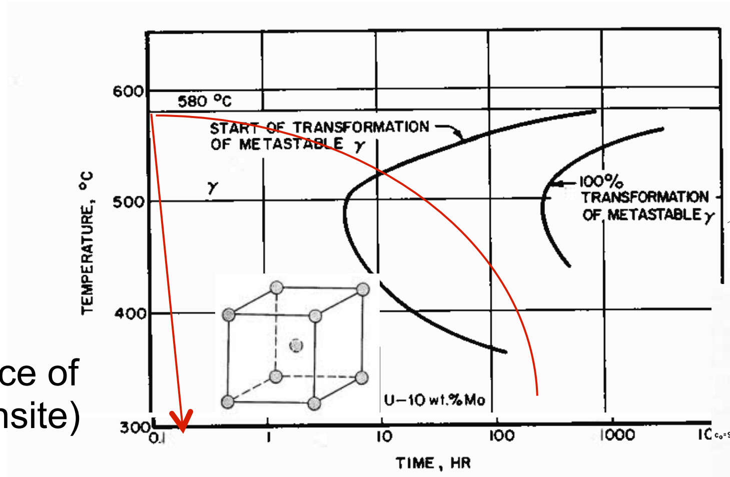


Fig. 3-1. Crystal structure of alpha uranium.

(absence of
martensite)



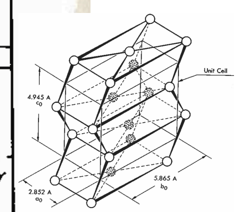
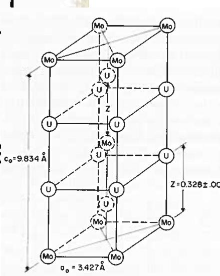
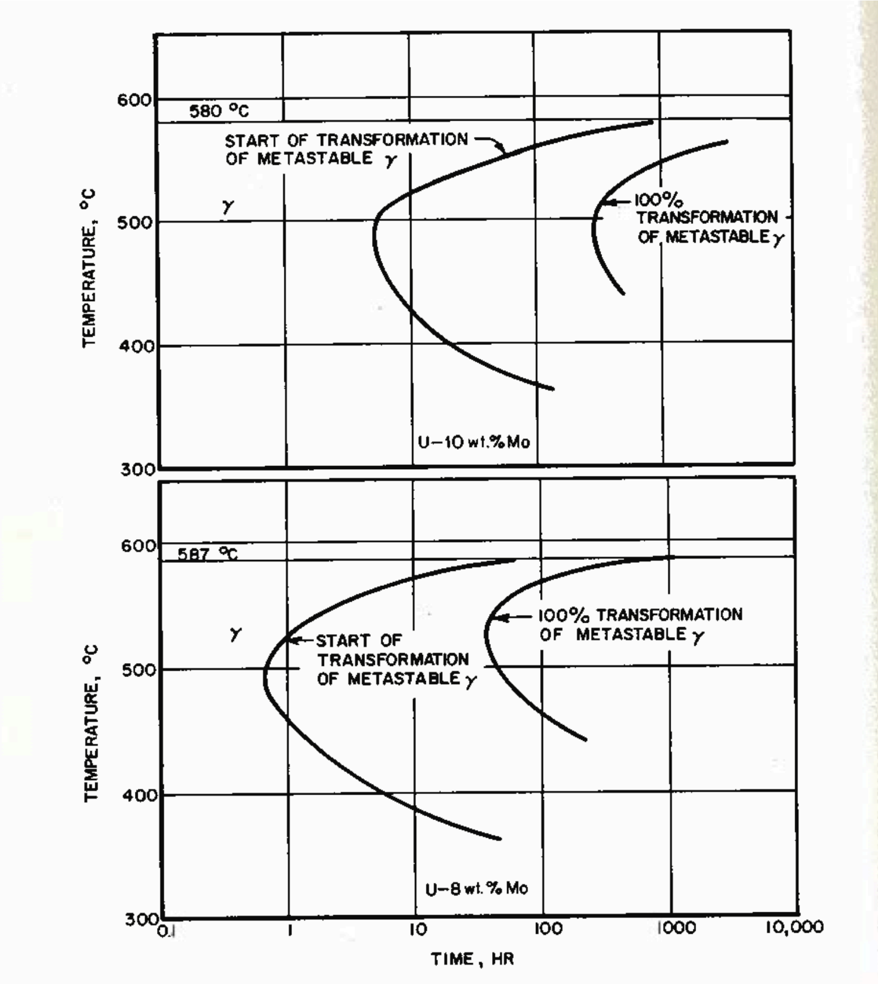


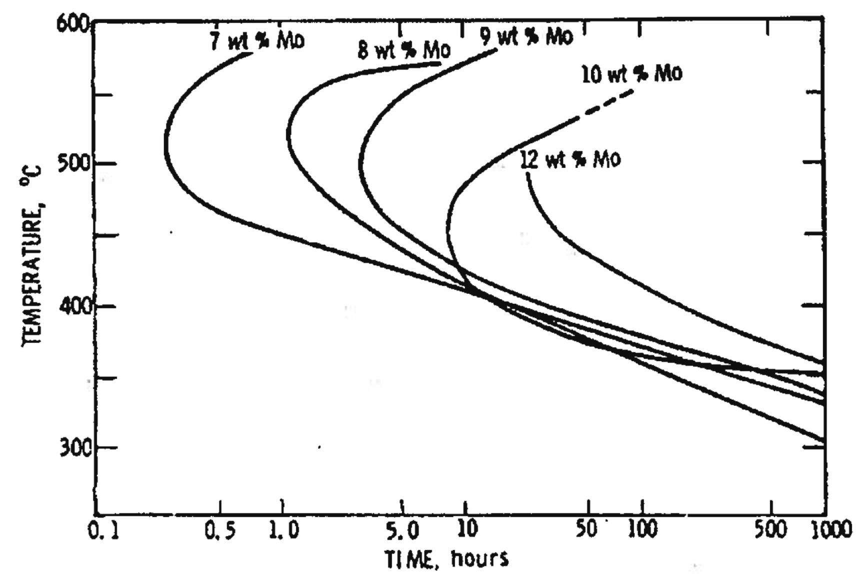
Fig. 3-1. Crystal structure of alpha uranium.



Time-Temperature
Transformation Diagram
(kinetics diagram)

Mo additions influence time to transform

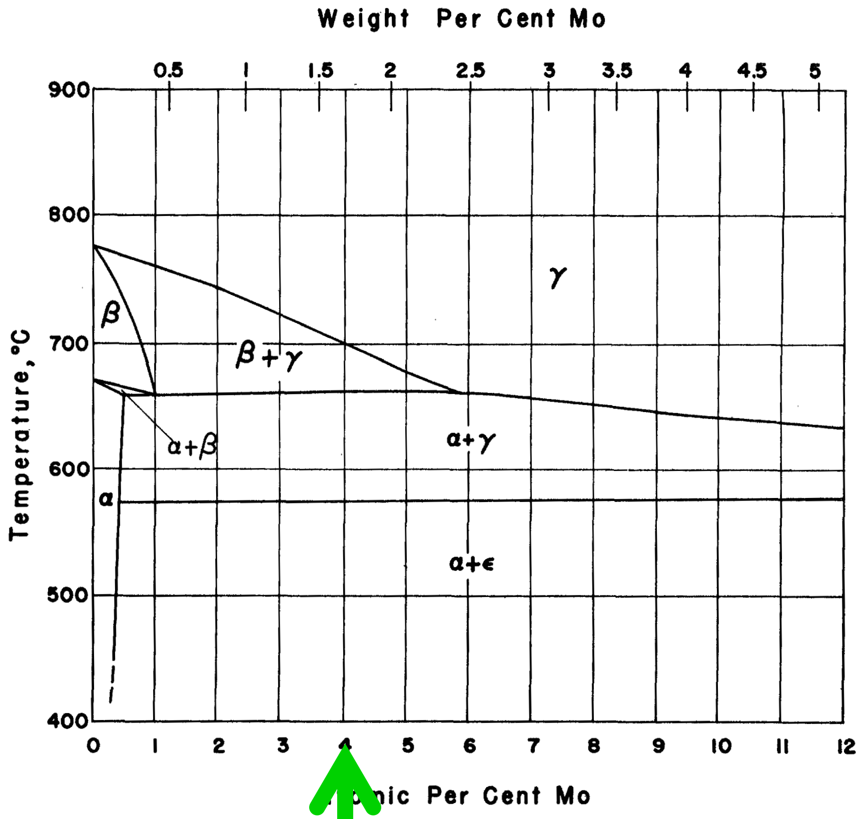


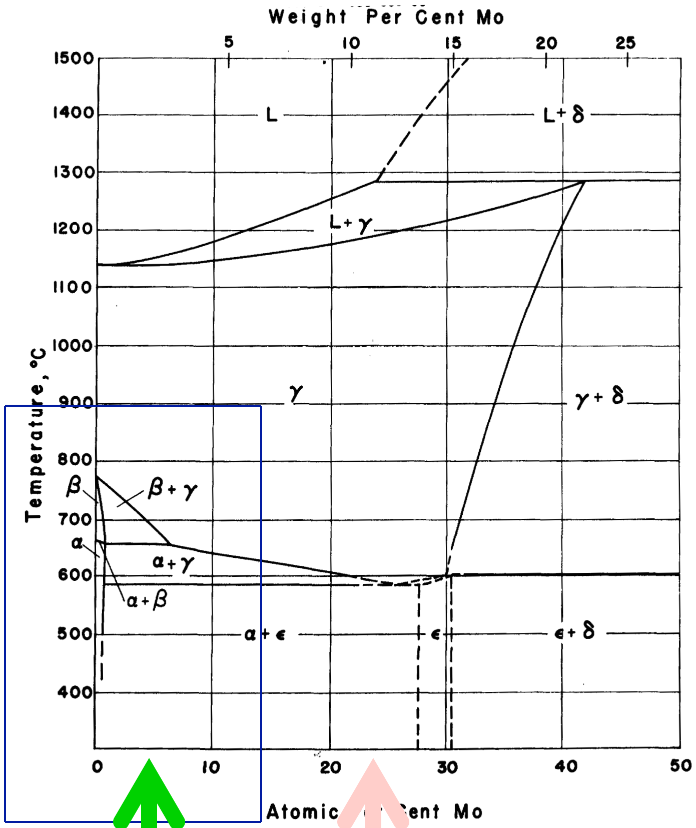


(start times alone)

SPR III was operationally kept below 300C.

U-1.5Mo is very different from U-10Mo



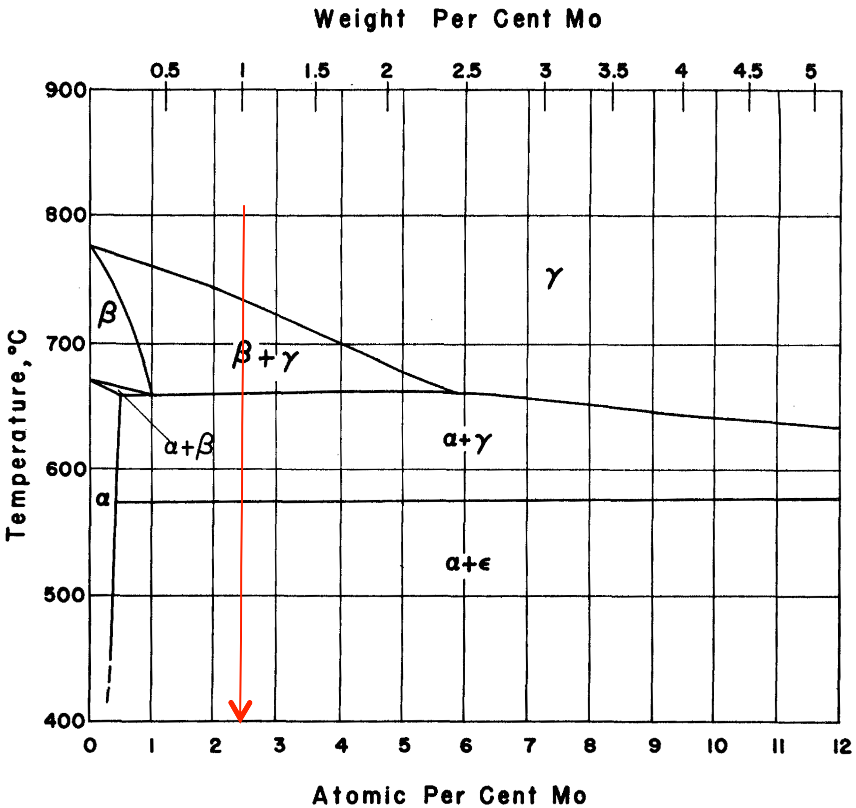


Godiva IV

Godiva IV

U-10 Mo

Low Mo alloys are not able to retain high temperature phase(s) upon quenching



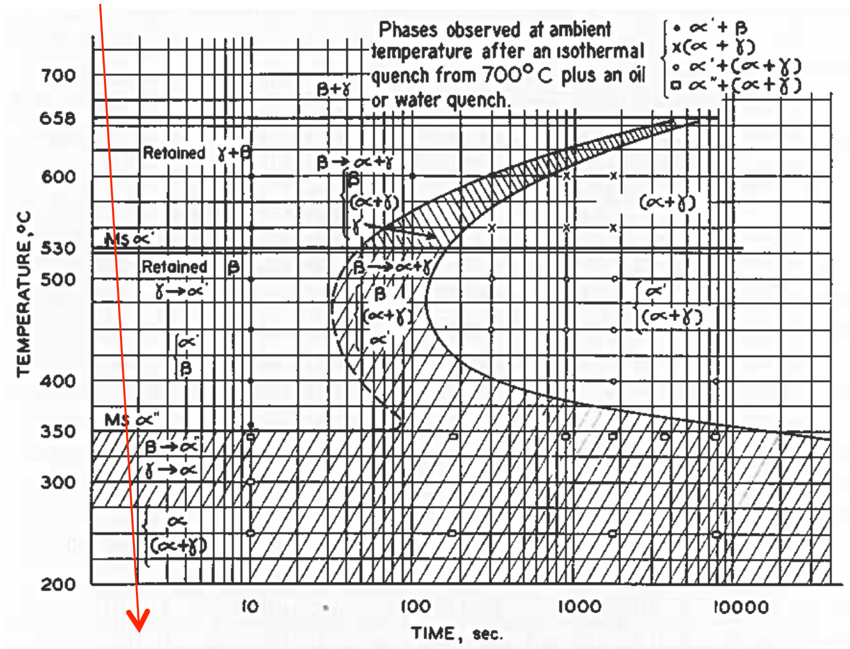


Fig. 128. TTT curves for U-1.0 w/o Mo alloy according to Lehmann.[316]

Martensite (strained orthorhombic, α') is the metastable phase
Orthorhomibic (α) plus U_2Mo (ε) are equilibrium phases

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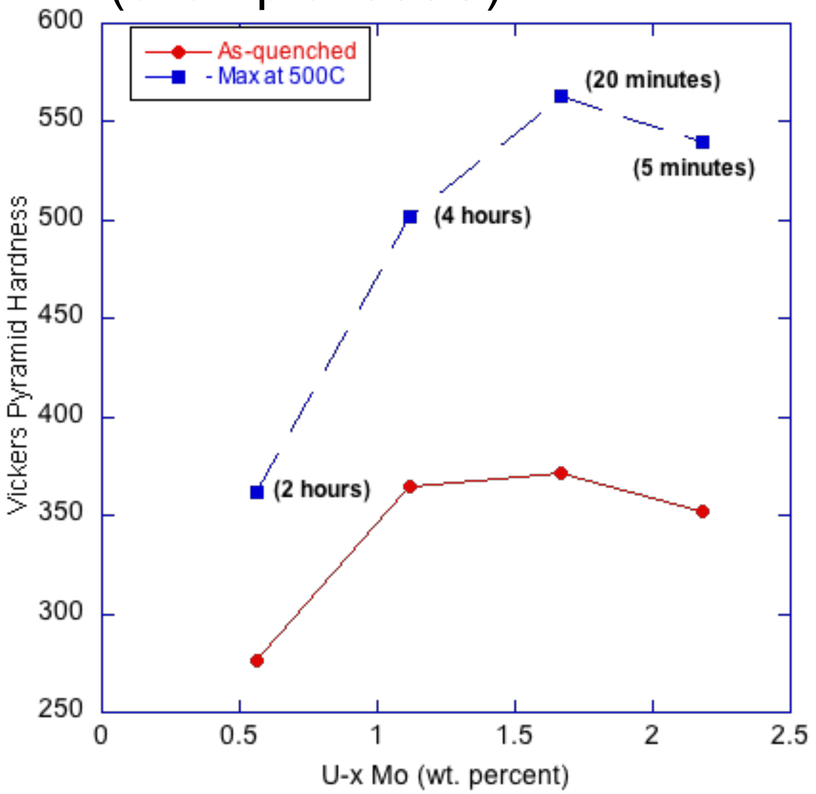
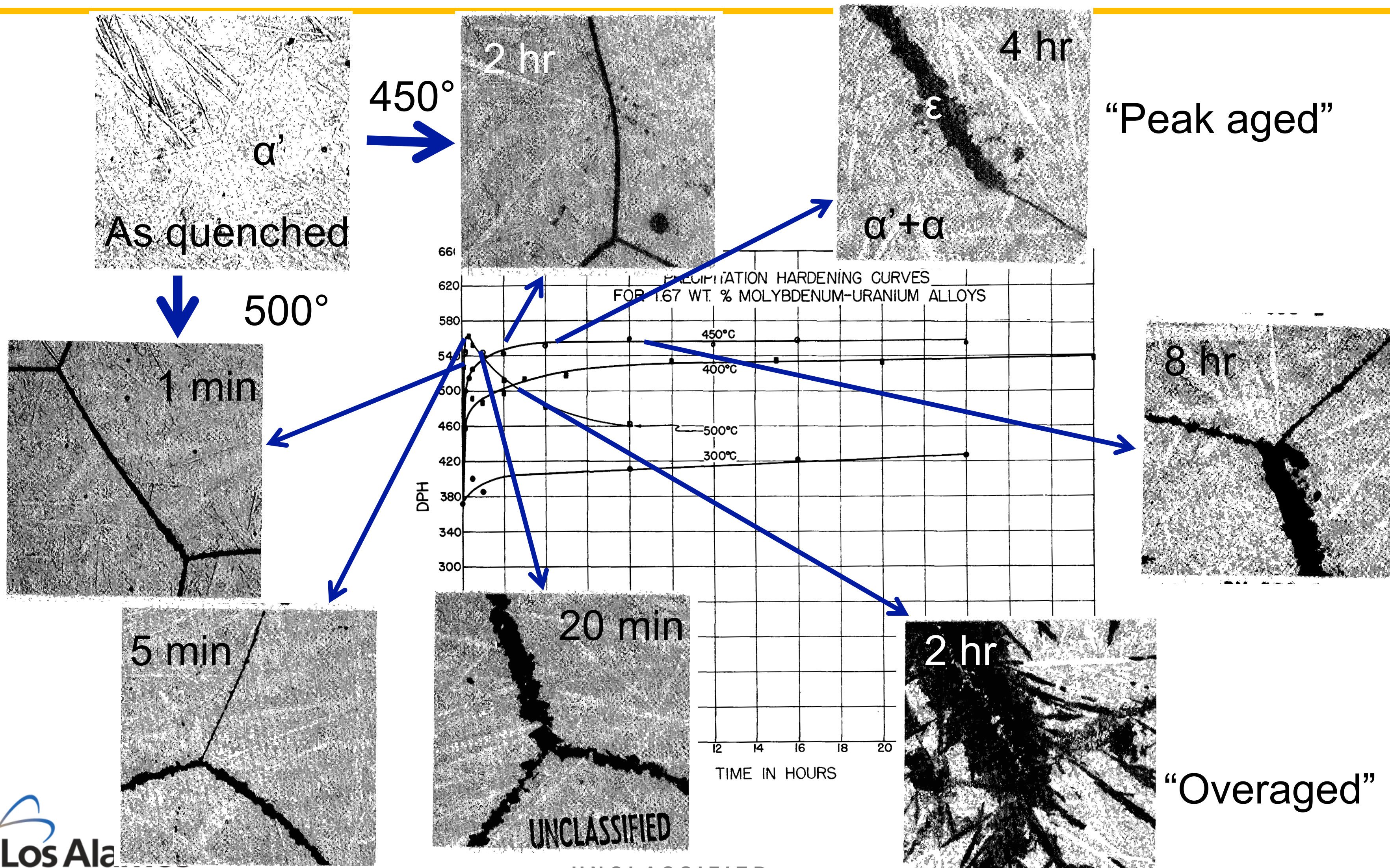
U-Mo alloy development at LANL in early 1950's

- **Alloys:**
  - U-0.56 Mo
  - U-1.12 Mo
  - U-1.67 Mo
  - U-2.18 Mo
- **Heat Treatment Temperatures**
  - 300°C
  - 400°C
  - 450°C
  - 500°C
- **Heat Treatment Times**
  - One minute to 24 hours

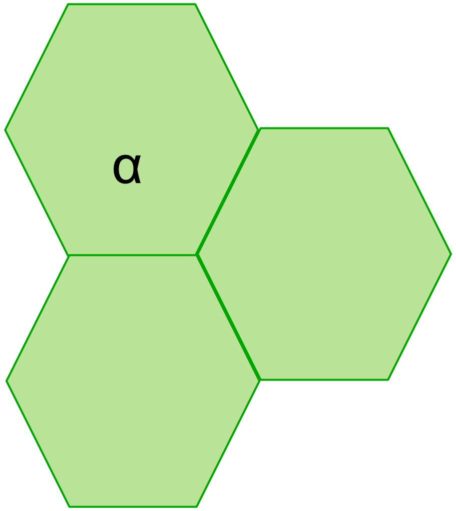
(example: 500C)



Precipitation hardening of U-1.67Mo

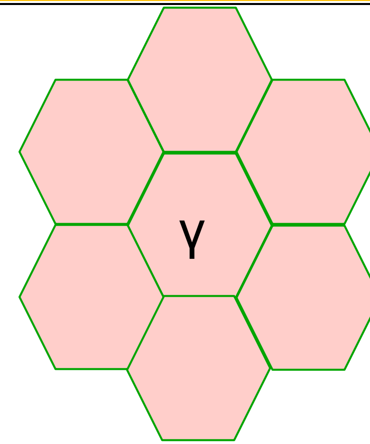


Summary of historical fast burst reactor metallurgy: Influence of uranium microstructure on performance

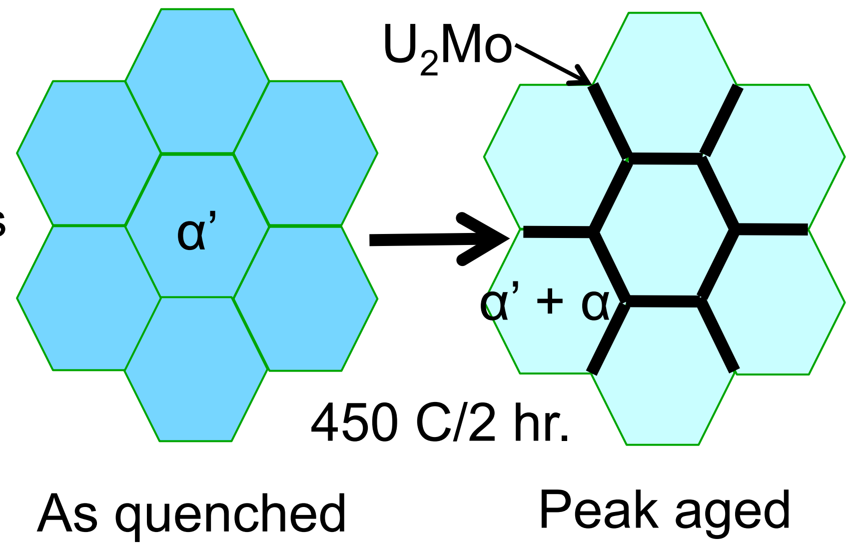


Unalloyed uranium
- Large grained
- Aniostopic alpha
- Poor properties

U-10 Mo
- Fine- or large-grained
- Isotropic gamma
- Good properties



U-1.5 Mo
- Fine-grained
- Anisotropic α plus gb cushion
- Excellent properties

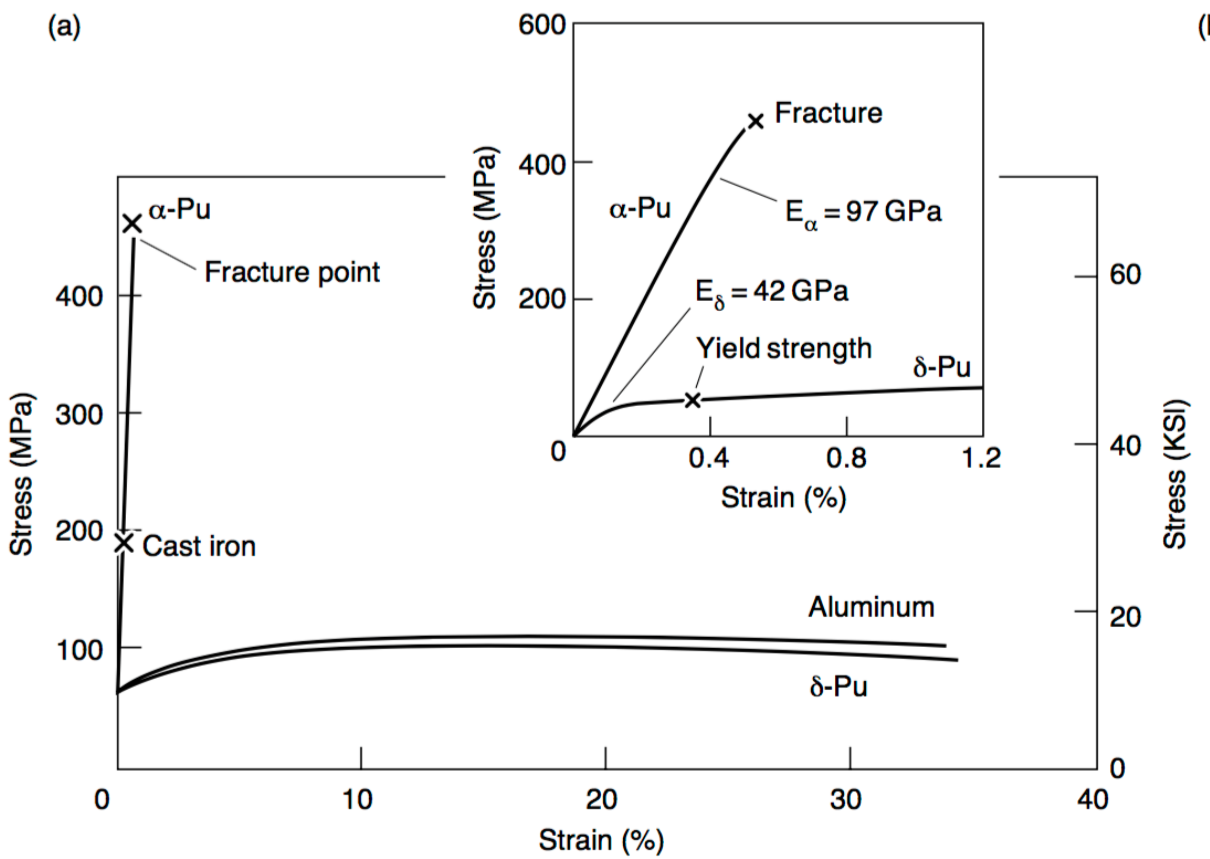


Design considerations for a burst reactor

- **High fissile atom density (favors metals, low-composition alloys)**
- **Oxidation resistance**
- **“Strong” (high yield point)**
- **“Tough” (some ductility)**

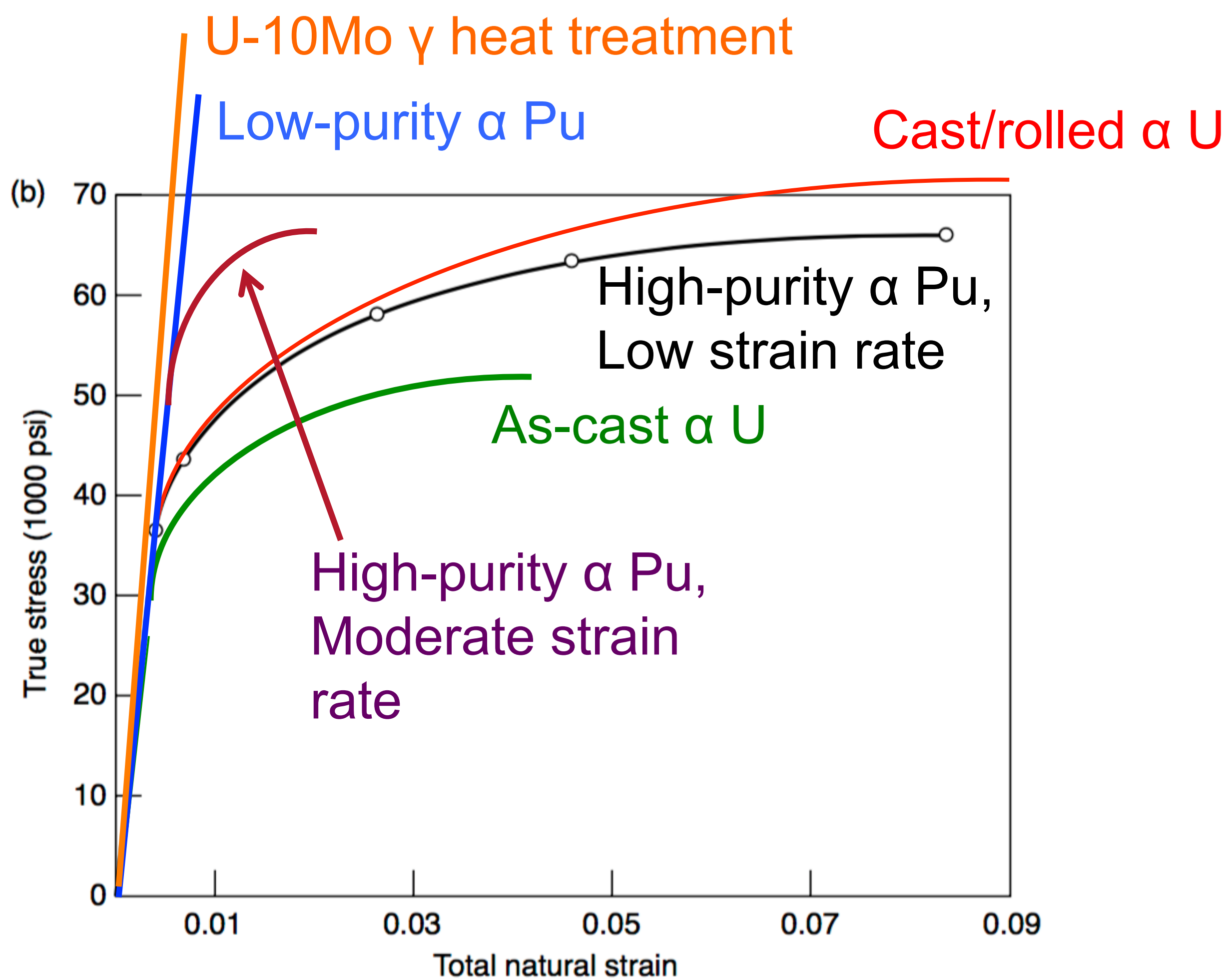
- **Tools for the metallurgist**
  - Alloying
  - Mechanical working
  - Heat treatment

How would one hypothetically design a Pu burst reactor?

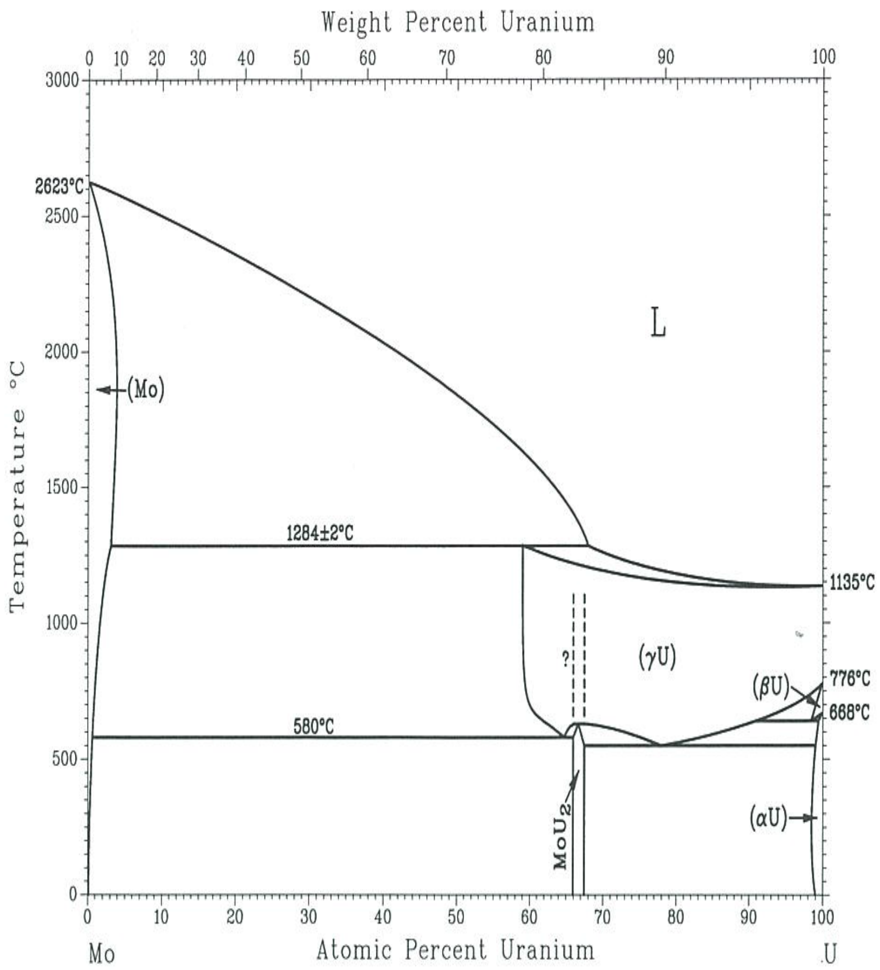


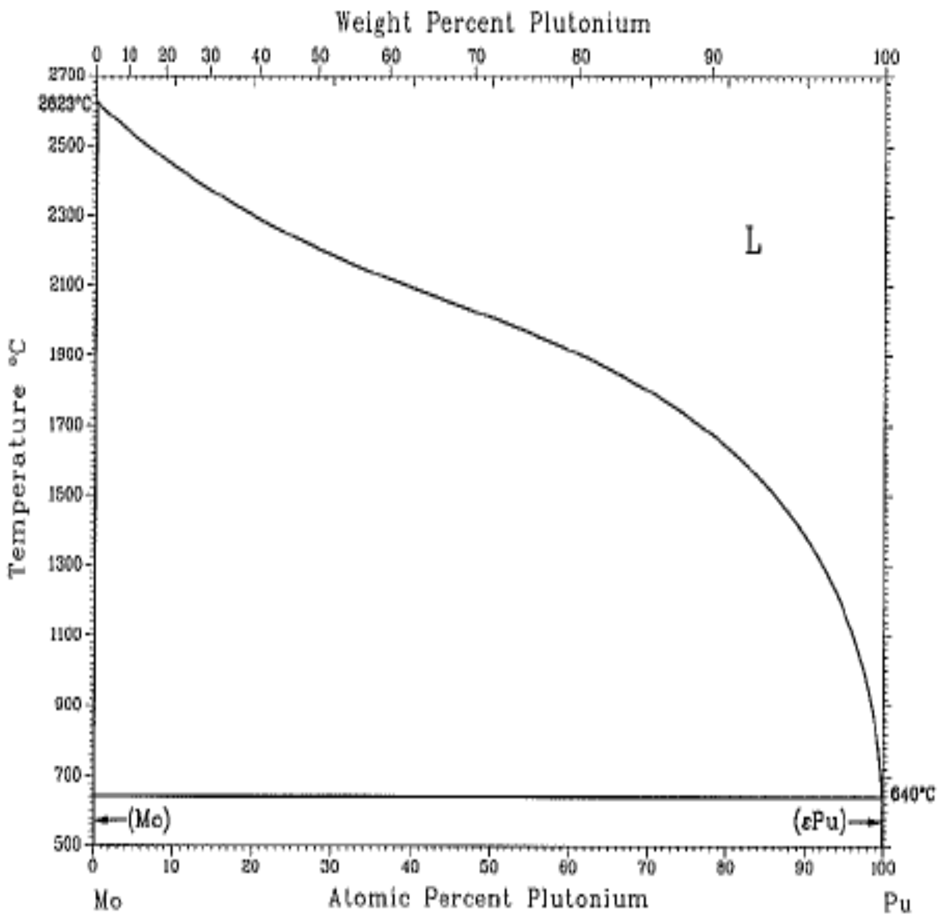
Pu mechanical properties depend greatly on phase

Stress-strain data for U, U-Mo, Pu

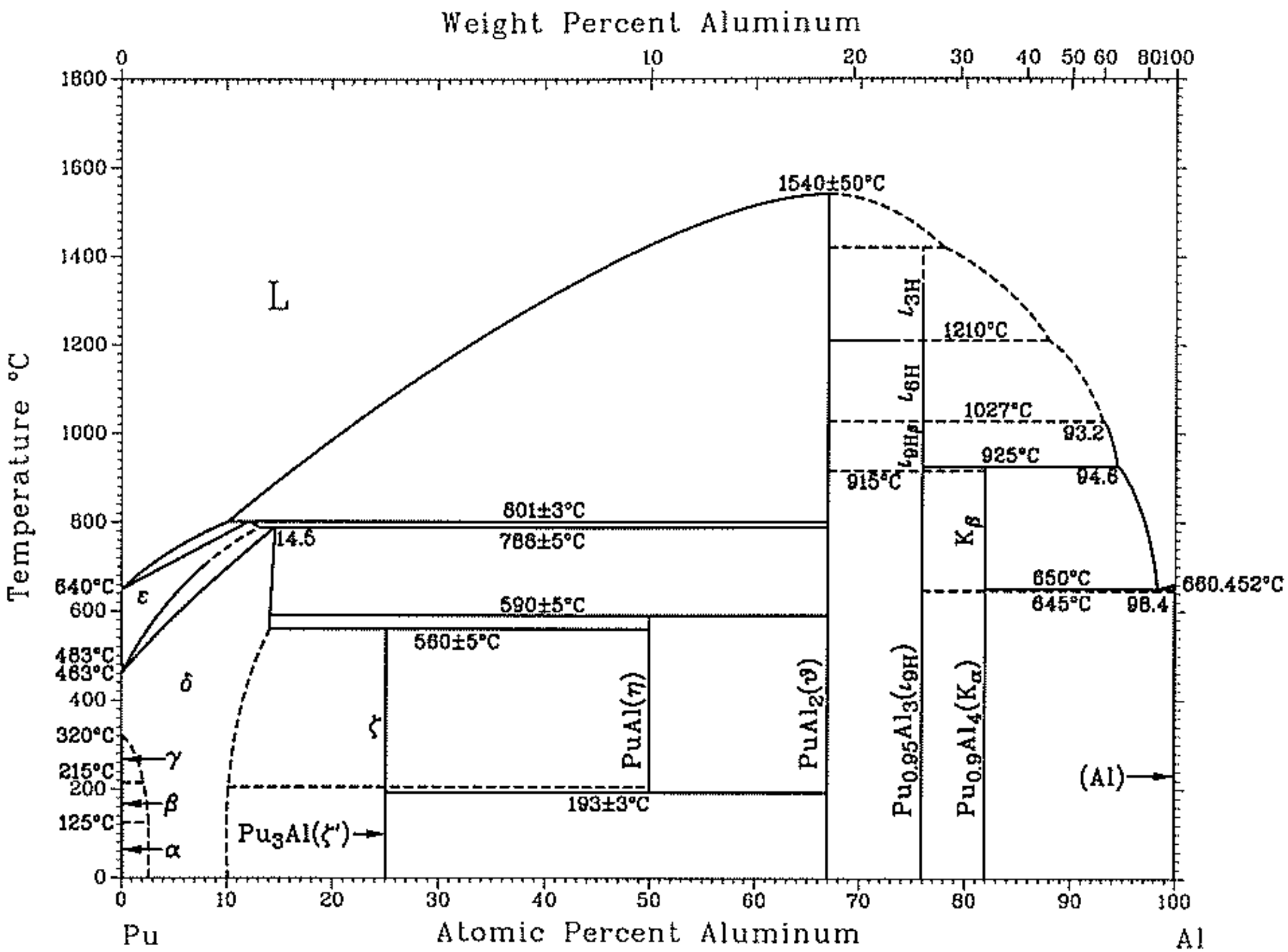


U-Mo and Pu-Mo phase diagrams

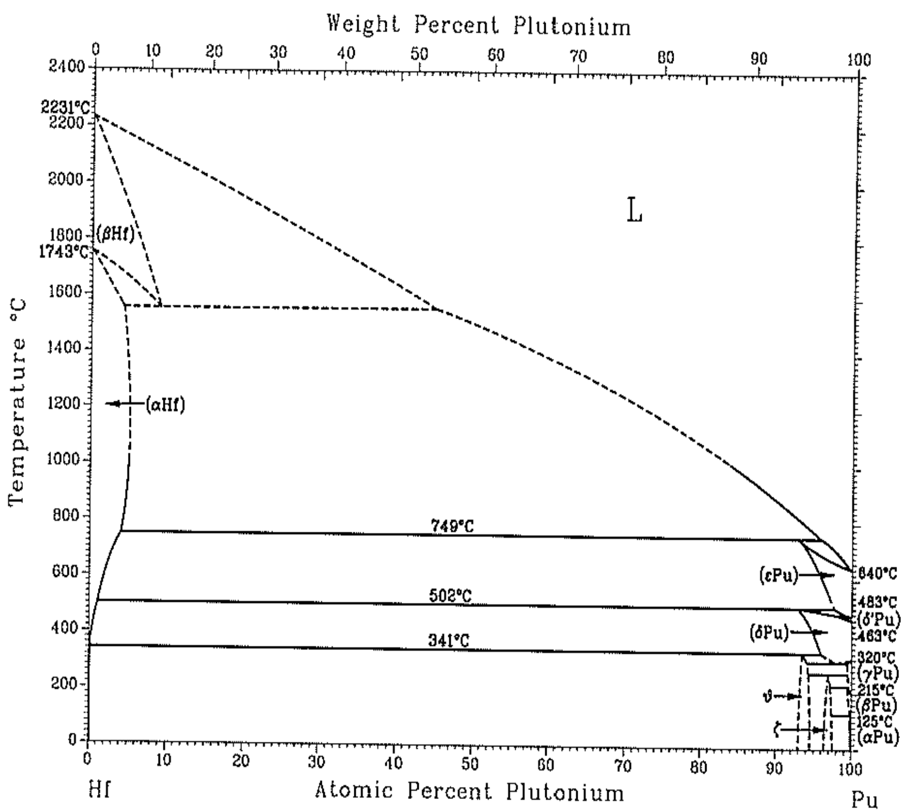


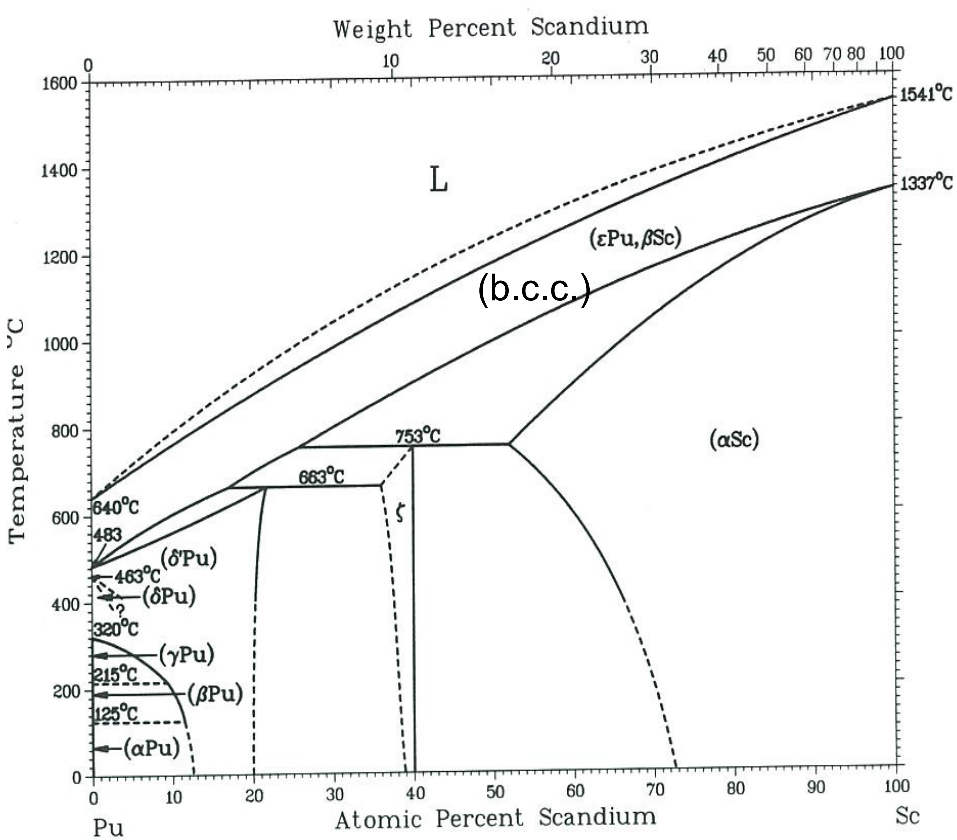


Pu-Al phase diagram

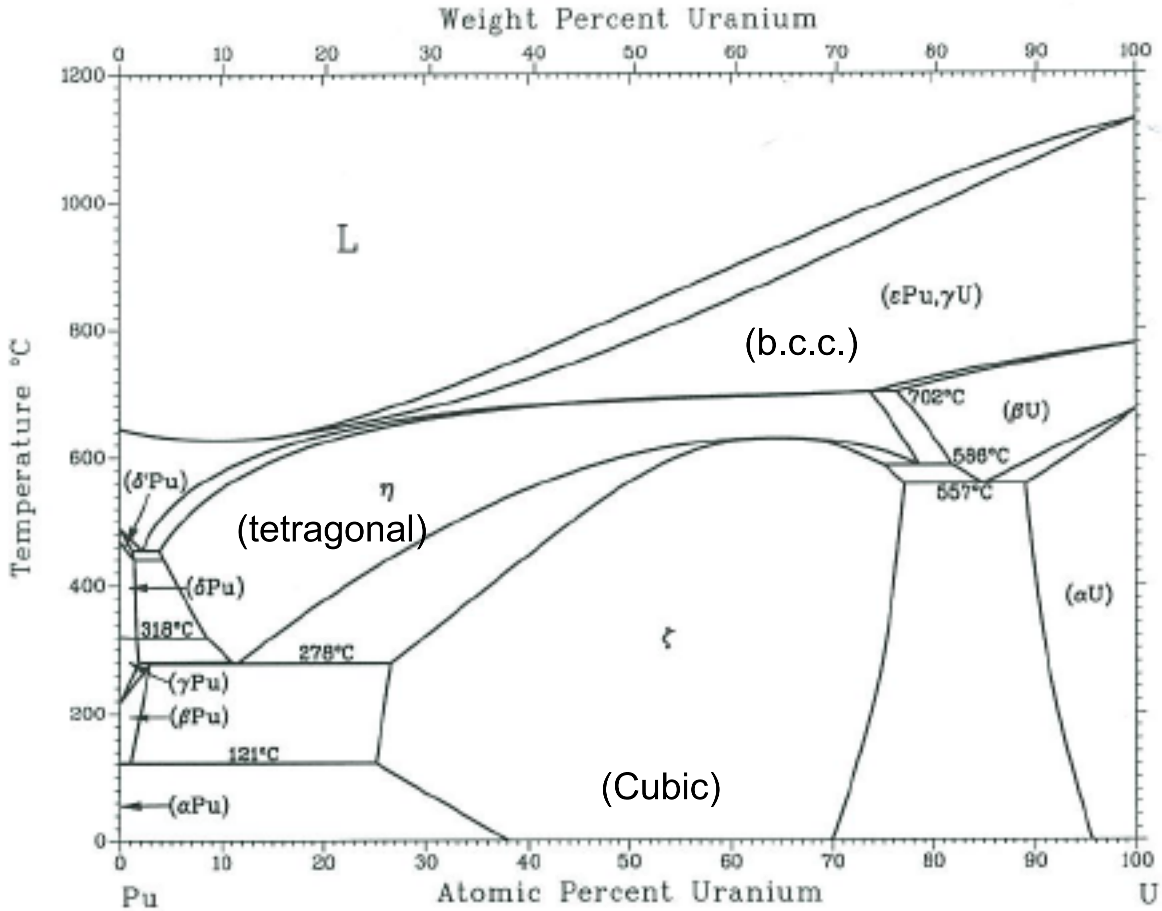


Pu-Hf and Pu-Sc phase diagrams

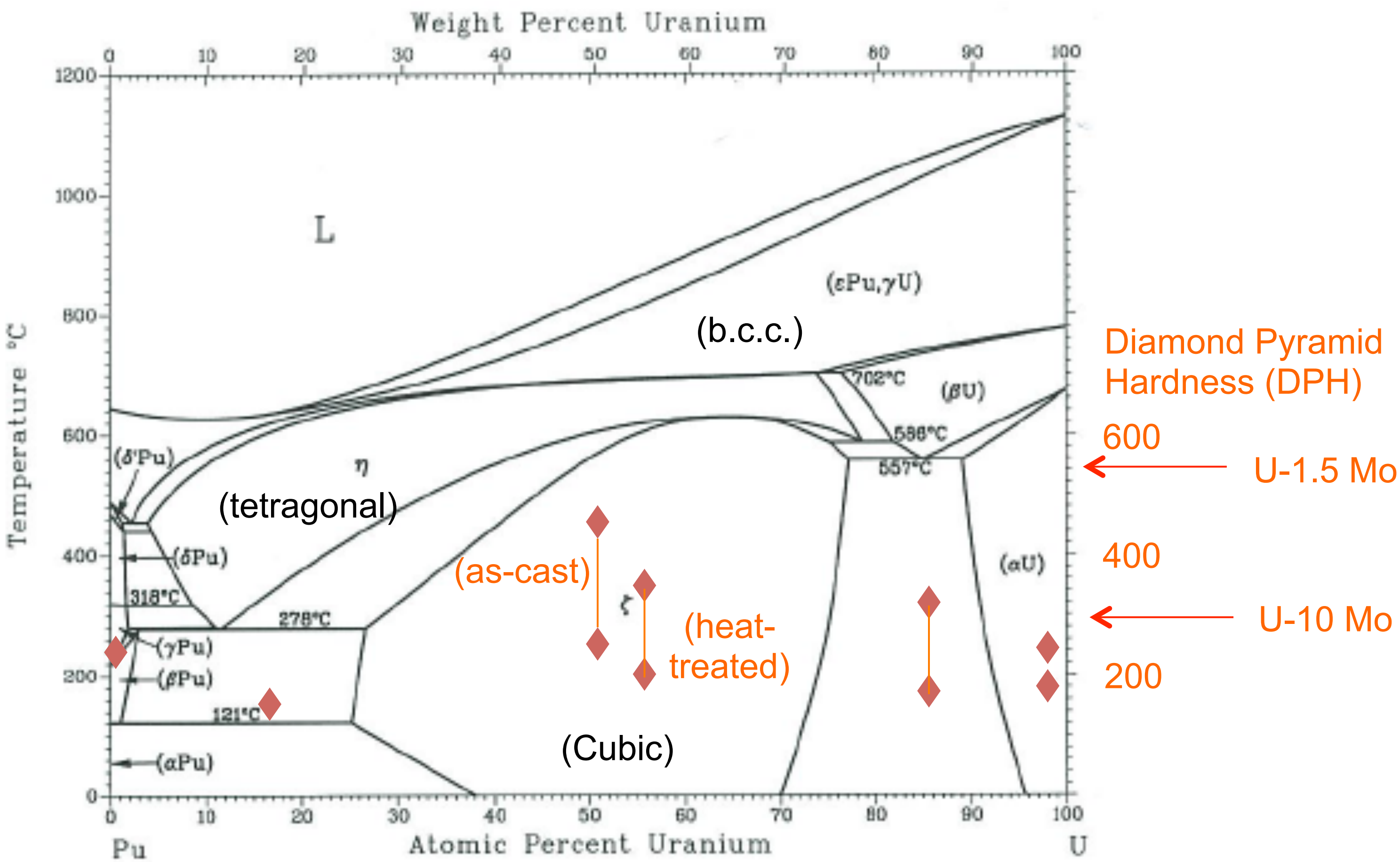




Pu-U phase diagram



Pu-U phase diagram

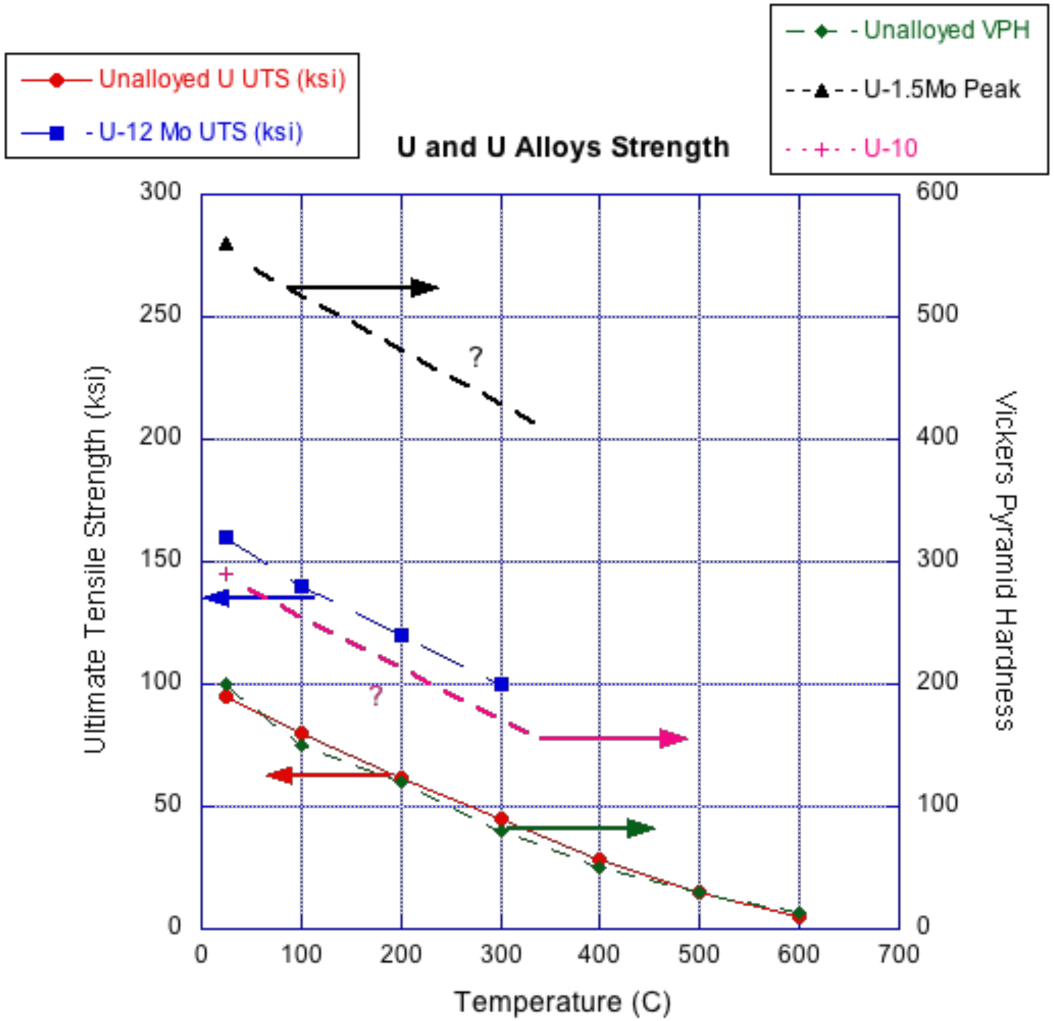


Summary

- **U-Mo systems have demonstrated superior performance in fast burst reactor applications**
- **Godiva U (U-1.5Mo) has proven especially robust**
- **Far less data exists for Pu systems**

Acknowledgements
♣ This work was supported by the DOE Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.

Strength variation with alloy content and temperature



Operated by Los Alamos National Security, LLC for NNSA

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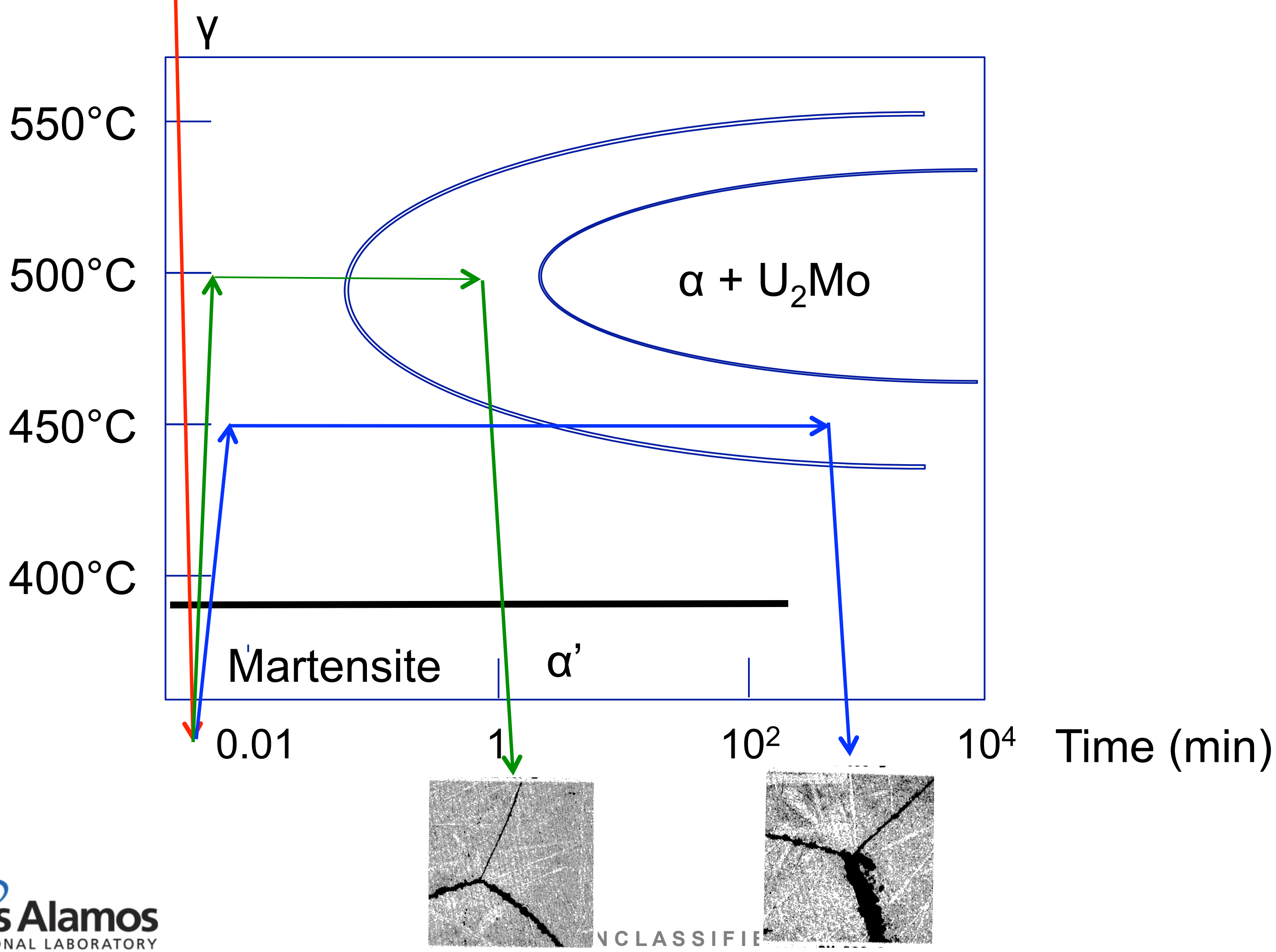
Postulated TTT diagram for U-1.67 Mo



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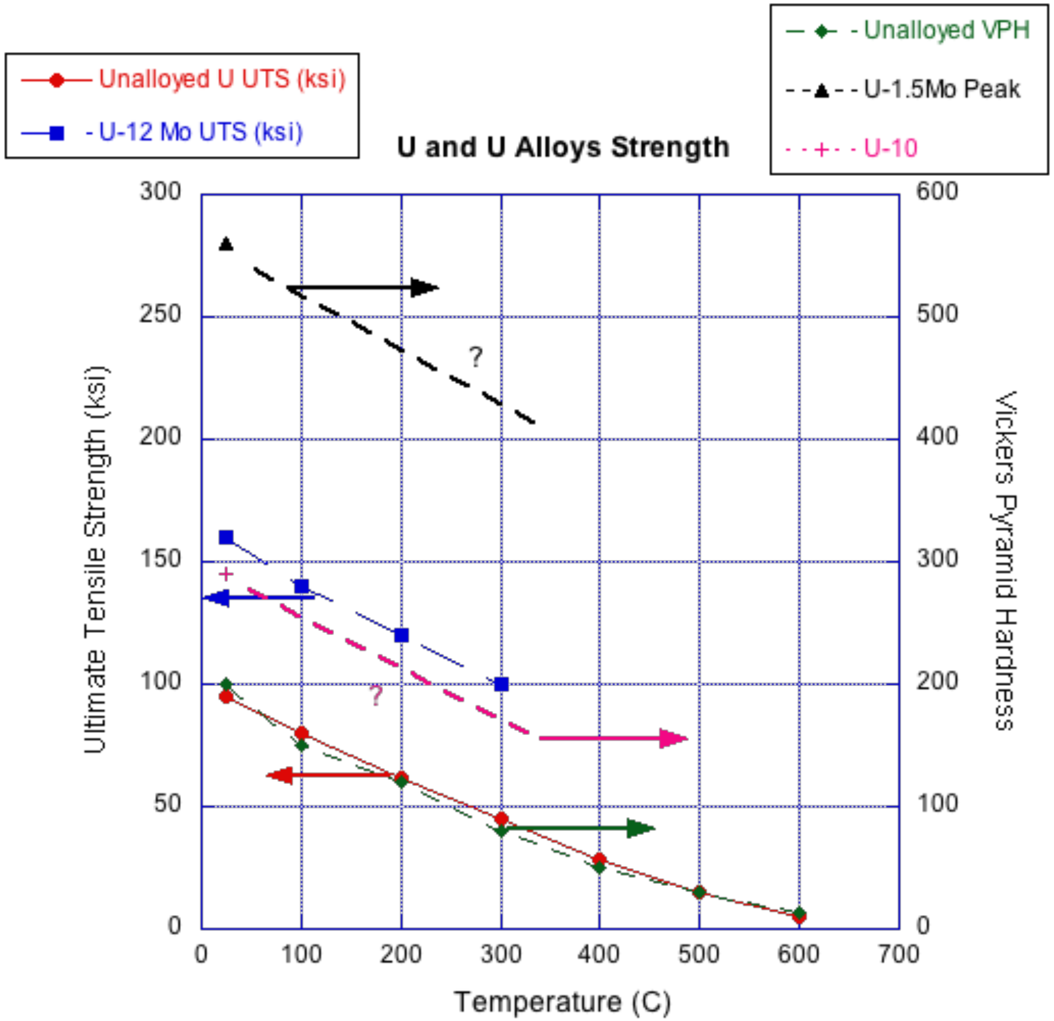
Strength variation with alloy content and temperature



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